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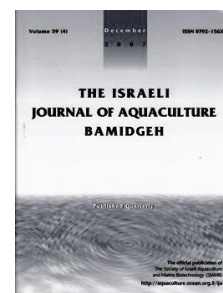
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Effects of Dietary Niacin on Growth Performance, Serum Biochemistry, Antioxidant Ability of Liver, Intestinal Digestion, and Absorption in Juvenile Golden Pompano

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Keywords: *Trachinotus ovatus*; growth performance; serum biochemistry; hepatic antioxidative ability; intestinal digestion and absorption; niacin requirement

Abstract

Six groups of experimental diets containing different levels (14.9, 22.4, 28.6, 37.9, 42.0 and 77.5 mg/kg) of niacin were formulated. Juvenile golden pompano (initial body weight: 7.82 ± 0.07 g) were fed in cages for eight weeks. Results showed that moderate niacin in the diet significantly increased ($P < 0.05$) weight gain rate (WGR), specific growth rate (SGR), and feed efficiency (FER). Dietary niacin levels increased the protein content in whole fish and muscle ($P < 0.05$). The content of serum high density lipoprotein cholesterol (HDL-C) and total cholesterol (TCHO) increased significantly and triglyceride (TG) content decreased significantly ($P < 0.05$). C3 and C4 content in serum, and activities of lysozyme (LZM), and alkaline phosphatase (ALP) increased significantly ($P < 0.05$). Dietary niacin levels significantly increased ($P < 0.05$) the catalase (CAT), alkaline phosphatase (ALP), and total antioxidant capacity (T-AOC) of the liver when niacin content was more than 28.6 mg/kg. Dietary niacin levels also improved intestinal digestion and absorption by increasing glutamyl transferase (γ -GT) activity. Quadratic regression analysis on WGR indicated that the optimum dietary niacin level for optimal growth of juvenile golden pompano was 29.85 mg/kg.

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Introduction

Niacin is also called vitamin B₃ or nicotinic acid. Niacin is one of eight B vitamins with the simplest structure and the most stable physical and chemical properties (Liu et al., 2019). Niacin is a precursor of two coenzymes: nicotinamide adenine dinucleotide (NAD) and nicotinamide adenine dinucleotide phosphate (NADP) (Hansen et al., 2015). Niacin is closely related to lipid metabolism, amino acid and protein metabolism in animals (Hansen et al., 2015, Luo et al., 2017). It has a positive effect on increasing high-density lipoprotein cholesterol (HDL-C) and decreasing triglycerides (TG) (Domanico et al., 2015, Le et al., 2015).

Certain fish are unable to synthesize niacin or synthetic content which cannot sustain the growth of fish because of the limitations of converting tryptophan to niacin (Mohamed and Ibrahim, 2015, NG et al., 1997). In most animal feeds, tryptophan is only present in small amounts (De Silva and Anderson, 1995). In fish, incorrect quantities of niacin can lead to refusal of feed, weight loss, skin hemorrhage, anemia, and other deficiencies (Shiau S Y & Suen G S., 1992, NRC, 2011). It has been reported that supplemental niacin in feed could increase weight gain rate of fish (Liu and Wen, 2016) however too much niacin in feed will inhibit the growth of fish (Poston and Combs, 1980). Nevertheless, there are no reports confirming that niacin is necessary in the formulation of golden pompano diet or of the effects of niacin on golden pompano. Nowadays, niacin requirement has been studied in only a few fish species such as brook trout *Salvelinus fontinalis*, (Phillips Jr and Brockway, 1949), rainbow trout *Salmo gairdneri*, (Poston and Wolfe, 2010), Indian catfish *Heteropneustes fossilis*, (Mohamed and Ibrahim, 2015), African catfish *Clarias gariepinus* (Burchell) (Morris et al., 2010), and carp *Cyprinus carpio* var. *Jian* (Xiang et al., 2008).

Golden pompano is a popular marine fish. It has a rapid growth rate, high flesh quality and is suitable for cage culture (Du et al., 2011). The purpose of this study was to quantify the niacin requirement for golden pompano according to data for growth performance, serum biochemistry, and relational enzymatic activity. This will provide a theoretical basis for feed formulation.

Materials and methods

Experimental diets.

Formulations of the basic diets are given in Table 1. Six experimental diets were formulated supplementing graded levels of 0, 7, 14, 21, 28, 63mg/kg niacin. Diet ingredients were purchased from companies in the People's Republic of China. Vitamin-free casein, soy protein concentrate, and fishmeal was used as dietary protein. Fish oil and soybean lecithin were used as lipid sources. Crude protein, crude lipid and ash content were 43.59 %, 12.15%, and 6.04%, respectively and were considered to provide enough nutrition value for the growth of golden pompano (Lin et al., 2015). Niacin content was 14.9 mg/kg (diet-1), 22.4 mg/kg (diet-2), 28.6 mg/kg (diet-3), 37.9 mg/kg (diet-4), 42.0 mg/kg (diet-5) and 77.5 mg/kg (diet-6) in the diets. These were determined by a liquid chromatography method (GB/T 14700-2002). All the ingredients were crushed into powder, passed through a 60-mesh sieve, thoroughly mixed with oil, and placed in a mincer. To these cold water was added to form a dough. The dough was then wet-extruded by a pelletizer (F-26, South China University of Technology, Guangzhou, China). The diets that were air-dried in an air-conditioned room contained approximately 10% moisture. Finally, all diets were placed into sealed bags and stored at -20°C until used.

Table.1 Formulation and proximate analysis of the basal diet

<i>Ingredient</i>	<i>Content/%</i>	
Casein	35.9	Note: 1. Vitamin premix provided the following per kg of diet: VB ₁ 25mg, VB ₂ 45mg, VB ₁₂ 0.1mg, VK ₃ 10mg, inositol 800mg, pantothenic acid 60 mg, folic acid 1.2mg, biotin 32mg, VD ₃ 5mg, VE 120mg, VC 2.0g, choline chloride 2.0g, ethoxyquin 150mg, avicel 14.52mg; 2. mineral premix provided the following per kg of diet: NaF 4 mg, KI 1.6 mg, CoCl ₂ •6H ₂ O(1%) 100 mg, CuSO ₄ •5H ₂ O 20 mg, FeSO ₄ •H ₂ O 160 mg, ZnSO ₄ •H ₂ O 100 mg, MnSO ₄ •H ₂ O 120 mg, MgSO ₄ •7H ₂ O 2.4 g, Ca(H ₂ PO ₄) ₂ •H ₂ O 6.0 g, NaCl 200 mg, zeolite powder 30.90 g
Soy protein concentrate	9	
Peanut meal	9	
Fishmeal	5	
Corn starch	23	
Fish oil	9	
Soybean Lecithin	2	
Choline chloride	0.1	
Vitamin premix (free niacin)	2	
Mineral premix	1	
Monocalcium phosphate	0.5	
Micro-cellulose	2	
Attractant	1.5	
Proximate composition/%		
Moisture	7.54	
Crude protein	43.59	
Crude lipid	12.15	
Ash	6.04	

Experimental procedure.

Juvenile golden pompano were obtained from Shenzhen Long Qizhuang Industrial Development Co., Ltd (China). Before the feeding trial, the fish were fed diet-1 in laboratory conditions for two weeks. At the beginning of the experiment, the juvenile golden pompano were fasted for 24 h and were then anesthetized with 100 mg/L eugenol (Shanghai Medical Instruments Co., Ltd, Shanghai, China). 360 fish (initial body weight: 7.82 ± 0.07 g) were stocked into 18 floating cages ($1 \times 1 \times 1.5$ m³; three cages per treatment) and 25 fish per cage. Each diet was randomly assigned to cages in triplicate. The fish were fed twice a day at 6:30 and 17:30 until apparent satiation on the basis of visual observation. Weight and number of dead fish, and feeding quantity were recorded every day. Water temperature ranged from 27.5-31.9°C, salinity 15-18‰, and pH 7.0-7.7 Dissolved oxygen content was > 6.0 mg/L., ammonia nitrogen was < 0.05 mg/L.

Sample collection.

Prior to sampling, fish were fasted for 24 h and were euthanized with 100 mg/L Eugenol (Shanghai Medical Instruments Co., Ltd., Shanghai, China). Average body weight and total number of fish in each cage were determined. Then two fish from each cage were sampled and stored at -20°C for analysis of whole-body composition. Five fish per cage were collected and blood was immediately sampled from the caudal veins with 2 mL heparinized syringes. Following centrifugation at 3000rpm for 15 min at 4°C, the serum was separated and stored at -80°C for analysis of serum biochemical indices and serum immune indices. Weight viscera and livers of the five fish were used for calculation of viscerosomatic index (VSI) and hepatosomatic index (HSI). Muscle samples from the dorsal sides were removed and stored frozen (-20°C) for further analysis. Three fish from each cage were sampled, and their liver and intestine collected. The liver and intestine samples were placed in a centrifuge tube, to which sterilized physiological saline (0.86%, pH 7.4) was added. The samples were then homogenized by a handheld homogenizer in an ice bath, respectively. The homogenate was then centrifuged for 20 min at 3000 r/min. The supernatant was removed for analysis of liver antioxidant ability and intestinal digestion and absorption, respectively.

Growth performance.

The following parameters were calculated:

Weight gain rate (WGR, %) in each cage = $[100 \times (\text{final body weight} - \text{initial body weight}) / \text{initial body weight}]$;

Specific growth rate (SGR, % /day) = $100 \times [\text{Ln}(\text{final individual weight}) - \text{Ln}(\text{initial individual weight})] / \text{number of days}$;

Feed efficiency ratio (FER) = $\text{wet weight gain (g)} / \text{dry diet feed (g)}$;

Condition factor (CF, g/cm³) = $100 \times \text{body weight (g)} / [\text{body length (cm)}]^3$;

Hepatosomatic index (HSI, %) = $100 \times \text{liver weight (g)} / \text{whole body weight (g)}$;

Viscerosomatic index (VSI, %) = $100 \times \text{viscera weight (g)} / \text{whole body weight (g)}$;

Survival rate (%) = $100 \times (\text{final number of fish}) / (\text{initial number of fish})$.

Whole body composition.

Two fish from each cage were dried in a muffle furnace (550°C) to measure moisture after which the samples were ground into powder. 2 g of this powder was used to measure ash content, 1 g was used to measure crude lipids with a Soxhlet extraction method, and 0.2 g to measure crude protein with a Kjeldahl method.

Serum biochemistry and immune response measurements.

The serum samples were sent to Xinhai Hospital to quantify serum triglyceride (TG), high density lipoprotein cholesterol (HDL-C), and total cholesterol (TC). The alkaline phosphatase (ALP), C3 complement (C3), C4 complement (C4) and lysozyme (LZM) were quantified using an assay kit produced by Nanjing Jiancheng Bioengineering Institute (China).

Hepatic antioxidative ability measurements.

The liver supernatant was used to quantify hepatic total antioxidant capacity (T-AOC), catalase (CAT), alkaline phosphatase (ALP), reduced glutathione (GSH) and glutathione reductase (GR) using an assay kit produced by Nanjing Jiancheng Bioengineering Institute.

Measurement of intestinal digestion and absorption.

The intestine supernatant was used to quantify intestinal chymotrypsin, γ -glutamyl transferase (γ -GT), amylase (AMS) and lipase (LPS) using an assay kit produced by Nanjing Jiancheng Bioengineering Institute.

Data statistics and analysis.

All statistical analyses were performed using SPSS 21.0 (SPSS Inc., Michigan Avenue, Chicago, IL, USA) for Windows. The results were expressed as the means \pm SD ($n = 3$) following a one-way analysis of variance (ANOVA). A P-value of <0.05 was considered significant, and Duncan's multiple range test was used to rank the treatments. (Duncan, 1955). Quadratic regression model was performed by excel 2016 to estimate the optimum dietary niacin level based on weight gain rate.

Results

Effect of dietary niacin levels on the growth performance of golden pompano.

Effect of dietary niacin levels on the growth performance of golden pompano is shown in table 2.

Table.2 Effects of dietary niacin levels on growth performance of juvenile golden pompano (*T.ovatus*)

Dietary niacin levels Mg/kg	Diet-1	Diet-2	Diet-3	Diet-4	Diet-5	Diet-6
	14.9	22.4	28.6	37.9	42	77.5
IBW/g	7.79 \pm 0.07	7.85 \pm 0.02	7.81 \pm 0.10	7.85 \pm 0.10	7.79 \pm 0.06	7.81 \pm 0.09
FBW/g	40.73 \pm 2.85 ^a	43.89 \pm 2.02 ^{ab}	48.79 \pm 4.45 ^b	49.13 \pm 3.28 ^b	49.24 \pm 1.98 ^b	47.92 \pm 3.87 ^b
WGR/%	425.19 \pm 35.86 ^a	458.77 \pm 24.55 ^{ab}	524.40 \pm 54.41 ^b	526.27 \pm 42.76 ^b	522.63 \pm 19.81 ^b	529.88 \pm 44 ^b
SGR/%/d	2.96 \pm 0.12 ^a	3.07 \pm 0.08 ^{ab}	3.27 \pm 0.16 ^b	3.27 \pm 0.12 ^b	3.27 \pm 0.06 ^b	3.21 \pm 0.13 ^b
FER	0.53 \pm 0.06 ^a	0.63 \pm 0.05 ^b	0.67 \pm 0.01 ^b	0.70 \pm 0.07 ^b	0.68 \pm 0.01 ^b	0.66 \pm 0.01 ^b
CF/g·cm ³	3.99 \pm 0.05	4.05 \pm 0.11	4.09 \pm 0.15	4.05 \pm 0.16	3.95 \pm 0.11	4.17 \pm 0.13
VSI/%	6.26 \pm 0.21	6.58 \pm 0.29	6.61 \pm 0.42	6.40 \pm 0.29	6.49 \pm 0.33	6.29 \pm 0.50
HSI/%	1.42 \pm 0.25	1.52 \pm 0.30	1.36 \pm 0.22	1.49 \pm 0.39	1.46 \pm 0.27	1.47 \pm 0.49
Survival/%	86.67 \pm 6.11	86.67 \pm 2.31	89.33 \pm 4.62	93.33 \pm 6.11	96.00 \pm 4.00	90.67 \pm 10.07

IBW: initial body weight; FBW: final body weight; WGR: weight gain rate; SGR: specific growth rate; FER: feed efficiency ratio; CF: condition factor; VSI: viscerosomatic index; HSI: hepatosomatic index.

Note: Data represents mean \pm SD of three replicates and values with different superscript letters within the same row are significantly different ($P<0.05$). The same case in the following tables.

Compared to group 1 and group 2, fish fed diet-3, diet-4, diet-5 and diet-6 niacin groups had a significantly higher WGR and SGR ($P<0.05$) but there was no difference among these groups. Dietary niacin significantly increased FER of golden pompano ($P<0.05$) and FER of diet-1 was lowest. There were no differences in CF, VSI, HIS and survival of golden pompano. Based on the WGR, the optimal dietary niacin requirement of golden pompano was estimated to be 29.85 mg/kg (Fig. 1).

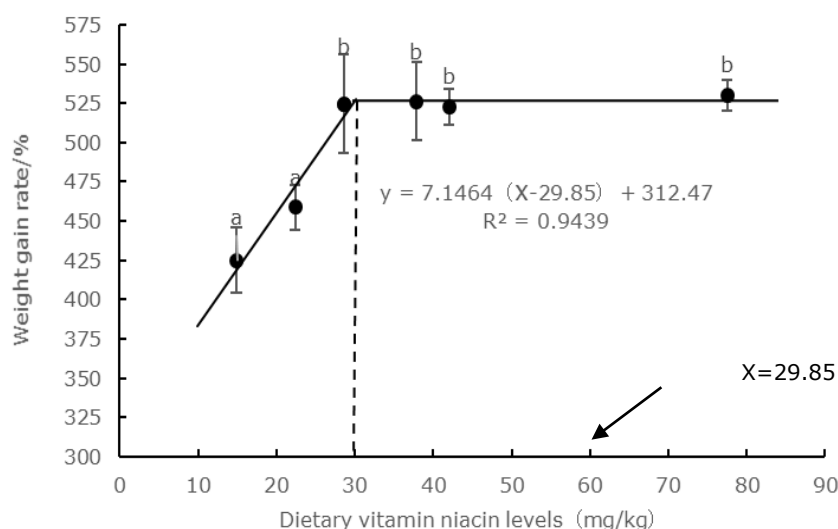


Fig.1 Relationship between the niacin content in the diet and weight gain rate. Each point represents the mean of three groups of fish ($n = 3$). Values with different superscript letters are significantly different ($P < 0.05$).

Effect of dietary niacin levels on the body composition of golden pompano.

Effect of dietary niacin levels on the body composition of golden pompano is shown in table 3. In the whole body, dietary niacin significantly increased crude protein content of golden pompano ($P<0.05$). There were no differences in moisture, crude lipid, and ash of golden pompano. In muscle, crude protein content of diet-2, diet-4, diet-5 and diet-6 had a significantly higher effect than diet-1 ($P<0.05$). Crude lipid of content of diet-2 and diet-3 were significantly higher than in diet-1 ($P<0.05$). There were no differences in moisture and ash.

Table.3 Effects of dietary niacin levels on whole body and muscle proximate composition of juvenile golden pompano (*T.ovatus*)

Dietary niacin levels mg/kg	Diet-1 14.9	Diet-2 22.4	Diet-3 28.6	Diet-4 37.9	Diet-5 42	Diet-6 77.5
Whole body						
Moisture	76.83±0.79	74.55±2.92	74.07±1.36	75.55±2.97	74.88±1.48	74.74±1.52
Crude protein	50.38±0.21 ^a	52.44±0.96 ^b	52.69±0.42 ^b	52.44±1.68 ^b	52.27±0.88 ^b	52.69±0.58 ^b
Crude lipid	12.11±0.68	12.08±0.68	12.16±0.03	11.75±1.52	12.12±0.12	12.58±0.77
Ash	4.58±0.02	4.52±0.15	4.57±0.10	4.53±0.04	4.55±0.02	4.52±0.04
Muscle						
Moisture	74.44±0.16	73.91±0.16	73.99±0.39	74.07±0.62	74.12±0.19	74.02±0.42
Crude protein	78.90±0.88 ^a	85.06±1.13 ^c	81.17±0.68 ^{ab}	81.46±1.29 ^b	82.06±2.10 ^b	82.81±1.10 ^{bc}
Crude lipid	9.97±0.53 ^{ab}	11.29±0.72 ^b	11.71±1.17 ^b	10.48±0.28 ^{ab}	9.44±1.60 ^a	9.38±0.57 ^a
Ash	6.46±0.17	6.61±0.08	6.33±0.10	6.49±0.19	6.73±0.14	6.38±1.18

Effect of dietary niacin levels on the serum biochemistry of golden pompano.

Effect of dietary niacin levels on the serum biochemistry are shown in Fig.2. Dietary niacin significantly decreased serum triglyceride (TG) of golden pompano ($P<0.05$). Total cholesterol (TCHO) of diet-2, diet-3, diet-4 and diet-5 were significantly higher than in diet-1 ($P<0.05$). Dietary niacin significantly increased serum high density lipoprotein cholesterol (HDL-C) of golden pompano ($P<0.05$).

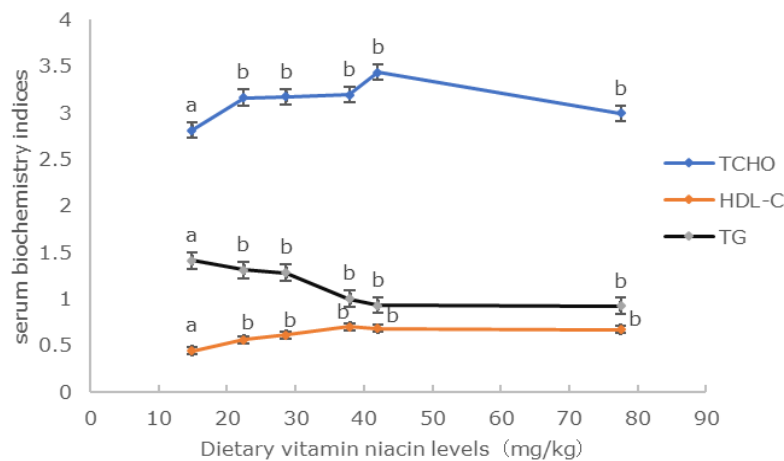


Fig.2 Effects of the niacin content in the diet on serum biochemistry. Each point represents the mean of three groups of fish ($n = 3$). Values with different superscript letters are significantly different ($P < 0.05$).

Effect of dietary niacin levels on the serum immune indexes and hepatic antioxidative abilities of golden pompano.

Effect of dietary niacin levels on the serum immune response of golden pompano is shown in table 4. Dietary niacin significantly increased the activities of serum LZM, ALP, C3 and C4 of golden pompano ($P < 0.05$). Dietary niacin increased significantly the activities of hepatic CAT, ALP and T-AOC when the niacin content is more than 28.6 mg/kg. Their activities increased in relation to increasing niacin level ($P < 0.05$) when content of niacin ranged from 14.9-28.6 mg/kg. After that they were stable with further increase of supplemented dietary niacin. There were no differences in hepatic GR and GSH of golden pompano.

Table.4 Effects of dietary niacin levels on serum immune and liver antioxidant capacity of juvenile golden pompano (*T.ovatus*)

Dietary niacin levels/ (mg/kg)	Diet-1 14.9	Diet-2 22.4	Diet-3 28.6	Diet-4 37.9	Diet-5 42	Diet-6 77.5
Serum						
LZM / $\mu\text{g/mL}$	164.94 \pm 8.93 ^a	226.40 \pm 4.17 ^b	228.55 \pm 11.89 ^b	236.35 \pm 21.70 ^b	229.91 \pm 14.17 ^b	230.59 \pm 26.31 ^b
ALP /U/L	4.26 \pm 0.07 ^a	4.90 \pm 0.75 ^a	6.62 \pm 0.26 ^b	6.65 \pm 0.69 ^b	6.71 \pm 0.40 ^b	6.63 \pm 0.18 ^b
C3/ $\mu\text{g/L}$	6.13 \pm 0.43 ^a	7.80 \pm 0.30 ^b	11.10 \pm 0.40 ^c	10.63 \pm 0.07 ^c	10.25 \pm 0.35 ^c	10.55 \pm 1.35 ^c
C4/ $\mu\text{g/L}$	34.83 \pm 3.02 ^a	47.02 \pm 4.35 ^{bc}	51.20 \pm 3.10 ^c	58.80 \pm 3.21 ^d	42.75 \pm 2.35 ^b	44.10 \pm 1.70 ^b
Liver						
CAT / U/mgprot	1.68 \pm 0.19 ^a	1.73 \pm 0.48 ^a	3.30 \pm 0.21 ^b	3.52 \pm 0.27 ^b	3.66 \pm 0.04 ^b	3.12 \pm 0.48 ^b
ALP / U/L	4.91 \pm 0.76 ^a	7.32 \pm 1.54 ^a	10.58 \pm 2.37 ^b	10.59 \pm 1.51 ^b	12.62 \pm 1.25 ^b	11.16 \pm 0.21 ^b
GR/U/gprot	0.89 \pm 0.10	0.87 \pm 0.16	0.89 \pm 0.14	0.85 \pm 0.12	0.83 \pm 0.04	0.93 \pm 0.04
GSH/ $\mu\text{mol/gprot}$	153.34 \pm 3.76	156.11 \pm 32.44	153.77 \pm 20.80	156.43 \pm 33.03	162.69 \pm 18.35	175.41 \pm 18.35
T-AOC/U/mgprot	6.22 \pm 1.64 ^a	27.66 \pm 3.64 ^c	24.85 \pm 2.17 ^{bc}	20.52 \pm 1.27 ^b	25.06 \pm 3.20 ^{bc}	22.67 \pm 4.69 ^{bc}

ALP, alkaline phosphatase; C3, C3 complement; C4, C4 complement; LZM, lysozyme; T-AOC, total antioxidant capacity; CAT, catalase; GSH, reduced glutathione; GR, glutathione reductase

Effect of dietary niacin levels on intestinal digestion and absorption of golden pompano.

Effect of dietary niacin levels on intestinal digestion and absorption of golden pompano is shown in table 5. Intestinal γ -GT activities of golden pompano fed diet-2, diet-3, diet-4, diet-5 and diet-6 were significantly higher than that those fed diet-1 ($P < 0.05$). There were no differences among supplemented groups. Dietary niacin levels had no effects on intestinal AMS, LPS and Chymotrypsin of golden pompano.

Table.5 Effects of dietary niacin levels on intestinal digestion and absorption function of juvenile golden pompano (*T.ovatus*)

Dietary niacin levels Mg/kg	Diet-1 14.9	Diet-2 22.4	Diet-3 28.6	Diet-4 37.9	Diet-5 42	Diet-6 77.5
AMS /U/gprot	51.98±4.72	49.15±7.56	51.95±9.47	48.32±7.61	47.98±7.27	48.65±1.27
γ-GT /U/mg	1.26±0.97 ^a	14.01±1.65 ^c	10.94±1.40 ^b	16.62±0.56 ^d	11.66±0.30 ^b	15.25±1.24 ^{cd}
LPS /U/L	188.52±28.53	179.32±19.51	165.69±11.39	173.20±25.71	181.79±26.90	174.64±34.75
Chymotrypsin /U/mgprot	0.75±0.16	0.59±0.11	0.54±0.12	0.54±0.13	0.51±0.08	0.57±0.12

γ-GT, γ-glutamyl transferase; AMS, amylase; LPS, lipase

Discussion

Growth performance is the most important parameter in determining the niacin (vitamin B) requirement in fish (Hansen *et al.*, 2015). Improvement in growth is attributed to the increased FER (Luo *et al.*, 2014). In our study, our results demonstrated that dietary niacin levels had a significant effect on WGR, SGR, and FER. The FER of golden pompano significantly increased when dietary niacin content ranged from 14.9-28.6 mg/kg and remained stable when the level was further increased. WGR and SGR of golden pompano showed a similar trend with FER. Furthermore, the results of fish body component analysis showed that adding niacin in the diet significantly increased protein content in the body and muscle of golden pompano. Lipid content of muscle also significantly increased when amount of niacin ranged from 14.9-28.6 mg/kg. The results showed that moderate amounts of niacin in diets improved growth and meat quality of golden pompano. The results obtained for GIFT tilapia (Jiang *et al.*, 2014), India catfish (Mohamed and Ibrahim, 2015, Ahmed, 2011), and rainbow trout (Poston and Wolfe, 2010) supported our study. In our study, golden pompano did not show niacin deficiencies such as skin hemorrhaging, anemia, and high mortality. This suggests that niacin in the basal feed was enough to overcome niacin deficiency symptoms.

Blood parameters are closely related to fish health and nutritional metabolism (Tan *et al.*, 2018). These are generally considered an important index to determine the effects of the fish dietary supplements on health status (Yue *et al.*, 2015). There have been few studies available on the effects of dietary niacin on plasma parameters of fish. In our study, serum HDL-C significantly increased when the content of dietary niacin ranged from 14.9-28.6 mg/kg and remained stable when higher levels were supplemented. Serum TG significantly decreased when the dietary niacin content was from 14.9-28.6 mg/kg and remained stable when elevated further in the feed. These results showed that blood lipid metabolism in fish improved when feed is supplemented with moderate niacin. The studies on GIFT tilapia (Jiang *et al.*, 2014) and juvenile *Ctenopharyngodon idellus* (Wu *et al.*, 2008) supported our study. Lipoprotein lipase (LPL) is the key enzyme involved in lipoprotein metabolism (Albalat A *et al.*, 2006). LPL is related to endogenous triglyceride metabolism in blood circulation (Yao *et al.*, 2009). LPL can promote the degradation of TG, and LPL is also involved in the conversion of Apolipoproteins and phospholipids between VLDL and HDL (Hu *et al.*, 2010). This may suggest that dietary niacin affected the content of serum TG and HDL-C by changing LPL activity in serum thus improving blood lipid metabolism of juvenile golden pompano. In our study, the content of serum TCHO also significantly increased with the content of dietary niacin. The result on GIFT tilapia (Huang *et al.*, 2013) supported our study. But the underlying mechanism as to how niacin affects blood indices of fish is not known, and further investigation is therefore required.

Nutritional factors have an important effect on immune and antioxidant ability in fish. Complementary systems (Holland and Lambris, 2002) have an essential effect on phagocytosis, microbial killing, immune complex clearance, and antibody production. Lysozyme is considered as non-specific innate immunity molecules that resist detrimental bacteria (Luo *et al.*, 2007). ALP is a non-specific hydrolase which plays a key role in growth, apoptosis, and signal transduction pathways (Jin *et al.*, 2015). CAT is also an important antioxidant enzyme, which can catalyze free superoxide anion radicals into

nontoxic compounds to reduce toxic effect (Tan et al., 2016). GSH is the major endogenous antioxidant scavenger that protects cells from oxidative stress (Sies, 1999). T-AOC reflected antioxidant capacity of fish. Previous research on young grass carp *Ctenopharyngodon idella* (Feng et al., 2016) demonstrated that niacin improved intestinal mucosal immune function. Similarly, in our study, the activities of LZM, ALP and C3 and C4 content in serum significantly increased when niacin content was more than 28.6 mg/kg in the diet, compared to that of group 1. Activities of CAT, ALP and T-AOC in the liver also significantly increased in relation to niacin inclusion in the diet compared to group 1. These results indicated that dietary niacin promoted immune tissue development by increasing LZM, ALP activity and the content of C3 and C4 in serum as well as increasing CAT, ALP and T-AOC activities in liver.

The intestine plays an important role in nutrient digestion and absorption in fish. γ -GT is a peptide transferase which is widely involved in intestinal absorption of peptides and amino acids (Xiang et al., 2008). AMS, LPS and Chymotrypsin are important digestion enzymes. In our study, the niacin supplemented groups had significantly higher γ -GT activity compared to diet-1 group. This agreed with results found in juvenile Jian carp (Xiang et al., 2008) and suggests that dietary niacin enhanced intestinal absorption through increasing γ -GT activity to a certain degree.

Conclusions

Four primary, novel, and interesting results presented in this study demonstrated that (1) Dietary niacin can significantly increase WGR, SGR, and FER of golden pompano when niacin content is more than 28.6 mg/kg.

(2) Dietary niacin significantly increases body protein content and improves the serum lipid metabolism of golden pompano.

(3) Diets supplemented with niacin significantly increased hepatic antioxidative ability and intestinal digestion and absorption of golden pompano.

(4) Quadratic regression analysis of weight gain rate indicated that the optimum dietary niacin level for optimal growth of juvenile pompano was 29.85 mg/kg.

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